The Battle of the Alchemists

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Herewith is presented a review of Man's accomplishments in the transmutation of the elements of our physical world, from the time of ancient mythology when the alchemists sought to transform lesser substances into gold and silver, down to the time of our present-day alchemists, the modern physicists. The goal of today's battle is not precious metals, but energy.

LONG, LONG AGO, when gods mingled among men, the god Hermes established the first laboratory on this earth and discovered many new and interesting substances by subjecting various kinds and mixtures of earth and rocks to the influence of fire or water. Not being blessed with the protection of the United States Patent Office, he kept his discoveries secret by putting his products into jars which were carefully closed and sealed. Hence arose the term "hermetically sealed," and the chemistry and metallurgy which thus sprang from the god Hermes was long known as the "hermetic art."

According to another legend, a group of wicked angels were expelled from heaven and settled on the earth, taking unto themselves human wives. To these wives the fallen angels disclosed the magic secrets of science, and the wives recorded these secrets in a book which was called "Chemna,"—the first handbook of chemistry. Thereafter those who practiced this art were called "alchemists." The ancient historian Tertullian tells of these fallen angels who thus revealed to mankind the knowledge of gold and silver, precious stones, and medicines.

However these things may be, there is ample documentary evidence from Egypt that alchemy was a flourishing science and art in Alexandria before the third century A.D., and it is probable that a famous book whose destruction was ordered by Diocletian in about 290 A.D. was one containing receipts and formulas for producing alloys to simulate gold and silver and for manufacturing artificial jewels.

These early alchemists, like modern chemists, were guided by a theory. Like our modern theories, theirs was imperfect and like ours it was an attempt to interpret and predict on the basis of a generalization of experience. They started with Aristotle's conception of 4 fundamental elements—earth, water, air, fire. These are not so different from, for example, the notion of the 4 states of matter proposed by Sir William Crookes, the solid state, the liquid state, the gaseous state, and the ionized state. The alchemists also believed that there was one basic entity, *prima materia,* which was identical in all bodies, but which took different forms according as it was brought into combination with one or more of the fundamental elements, earth, water, air, and fire. In our time, we recognize this *prima materia* to be electricity existing in 2 forms, electrons and protons. By action of earth, water, air, or fire on the various manifestations of the *prima materia,* these alchemists performed oxidation, reduction, solution, smelting, alloying. It is not to be wondered that they interpreted their work as a "transmutation of matter"; from their standpoint it was transmutation.

On account of the variety of colors which the compounds of mercury and sulphur exhibit, and their ease of chemical change, it is not surprising that those elements were of particular interest to the alchemists, and were supposed to be quite close to this *prima materia* which they sought. It is not so easy, however, to understand their choice of some of the other substances. For example, in the year 1250 Beauvais classified matter as consisting of 4 spirits and 6 bodies: The 4 spirits were mercury, sulphur, arsenic, and sal ammoniac; the 6 bodies were gold, silver, copper, tin, lead, and iron, of which gold and silver were pure and the rest impure.

In addition to this Greek background, which was gropingly scientific in its approach, the mystery and magic of the Orient were introduced from Arabia, Persia, and India as a result of the various wars and invasions. Thence came the notion of the "philosopher's stone" whose magic touch would transform common substances into gold. The philosopher's stone, perhaps, should be thought of as the first catalyst except that it was like the fountain of youth or the end of the rainbow, or the Utopia—only a beautiful product of the imagination.

In the rapid rise of chemistry during the 19th century, a beautiful and nearly perfect scientific theory of atoms and molecules was developed as a far extension of the ancient philosophical ideas of atoms advanced by Democritus. How sound was this theory, was demonstrated by the fact that it was only extended, but not essentially changed, when physicists devised methods of counting and weighing molecules individually, measuring their separate velocities and the energy and force required individually to pull them apart into their constituent atoms. The puzzles of the old alchemists were solved by the recognition of 2 classes of substances, elements and compounds, of which the former retain their identity throughout all action of earth, water, air, fire, or any other physical or chemical agent. Thus alchemy, which sought to transmute the elements, became supplanted by chemistry, which occupied itself with the various combinations of these elements to form chemical compounds. "Alchemy was dead: Long live chemistry!" But is this the end of the story?

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The textbook in which the author first studied chemistry in 1904 defined an atom as "an indivisible, indestructible, and unchangeable unit of matter." Yet 5 years *earlier* J. J. Thomson and his colleagues had split up atoms into electrons and positive ions and within 20 years it had come to be realized that the atom could be very changeable—could in fact exist in any one of an infinitely infinite variety of conditions commonly termed "excited states." Thus the atom is *not* indivisible and is *not* unchangeable, but these changes do not really affect the identity of the atom: the electrons which it loses come back to it or others take their places; it does not stay in its excited states very long, but reverts to its normal state usually within a hundred millionth of a second.

We must not despise the efforts of the early alchemists. Among them were numbered such great minds as Newton, Leibnitz and Boyle, all of whom studied and practiced alchemy, though they were beginning to realize its defects. But from this mixed ancestry of legend, experiment, and magic was born the science of chemistry!

In its ionization and its excited states the identity of the atom is like that of a man. You may cut off his hair or his nails, but they come back. You may even amputate a finger or a leg, but he is still the same man. Or you may excite him to a fit of anger or activity, but he cools down again. Through it all he retains his identity by virtue of that mysterious something that we call his soul. Now the soul of an atom is its nucleus. Through ionization and excited states this nucleus, so far as we know, remains unchanged. Until we know the nucleus of the atom we no more know the atom than do we know a man by his hair, nails, fingers, or legs. What do we know about the nucleus?

Beyond a doubt we know exactly the mass of every kind of atomic nucleus; we know that it is composed of a definite number of protons and electrons, and that it has a positive electric charge, which we know accurately. Thus the hydrogen nucleus consists of a single proton; the helium nucleus consists of 4 protons and 2 electrons and has a mass 0.77 per cent less than the sum of 4 hydrogen nuclei; the uranium nucleus consists of 238 protons and 146 electrons, etc. We know also that the nucleus is very small in comparison with the over-all atomic dimensions, i. e., much smaller than 10^{-10} cm in diameter—probably less than 10^{-11} cm.

We have good reason for thinking that some atomic nucleuses are magnets with a magnetic moment equal to that of one electron, and that this is true if there be an odd number of electrons in the nucleus. But some phenomena have not as yet been reconciled with this idea of the magnetic properties of the nucleus. Furthermore, there is reason to believe that the proton configurations in the nucleus also may contribute a magnetic moment, far smaller than that due to the electrons.

We know that atomic nucleuses are deformable under the action of intense forces, such as can be exerted only by electrified particles like alpha particles from radium, which are shot toward the nucleuses with such tremendous velocities that they may come very close before being deflected away by the repulsive force between nucleus and alpha particle. When their distances are greater than 10^{-10} cm this force varies inversely as the square of the distance, as nearly as we can tell; this shows us that the nucleuses are practically electrified points as far as distances greater than 10^{-10} cm are concerned. With closer approach, however, the force departs more and more from the inverse square law, showing that the nucleuses have a structure or arrangement of electricity within their tiny domains, and that this structure may be deformed by strong electrical forces. All of this information is inferred from studies of the angular distribution of scattering when alpha particles pass through thin films of matter.

We know that the nucleuses are seats of tremendous energies, as evidenced directly by phenomena of radioactivity and indirectly by certain aspects of the theory of relativity to which I will refer later. From radioactivity, also, we find that groups of 4 protons and 2 electrons (helium nucleuses) appear to be particularly stable configurations within the larger structure of the nucleuses of heavy atoms. We call these groups "alpha particles."

The atom is still the same old atom; and while its new attributes discovered by the physicists add to its versatility, they do not undermine its fundamental character of good old-fashioned chemical respectability.

Having said these things, we have told almost everything that is known about atomic nucleuses. Many other things we would tremendously like to know. How are the protons and electrons arranged in the nucleus? What is their state of motion? What forces hold them together? How is their energy stored away? Under what conditions can the nucleus be disrupted or this energy released, or the configuration changed? To all of these questions we must confess almost total ignorance.

Think for a moment what this ignorance implies. All of the positive electricity, most of the negative electricity, most of the mass and by far the greater part of the energy of the world reside in atomic nucleuses. We must confess, therefore, that we know as yet very little about most of the world of matter, electricity, and energy. This should make us rather careful about making such statements as one recently published by a leading exponent of the new school of theoretical physicists who wrote, "The underlying physical laws necessary for the mathematical theory of a large part of physics and the whole of chemistry are thus completely known . . . ." It should also warn us against such rash statements as "the breakdown of the law of causality" and "the law of conservation of energy does not apply to individual processes, but only statistically as an average."

A crude analogy will illustrate the relative ad-

vancement of our present state of knowledge of atoms. Liken the nucleus to a building and the extra-nuclear electrons to a group of pebbles resting on the steps of a fire escape on the outside of the building. As we observe these pebbles, we notice that from time to time a pebble falls from one step to another. We do not understand why it falls; hence we make various attempts to hypothecate some model or mechanism that will explain the dropping of these pebbles. Bohr, Sommerfeld, Langmuir all take their turn, but none of them invents a mechanism that satisfies all of the observations. We become discouraged with model building. Finally a brilliant young man, Heisenberg, proposes that we do away with models entirely and concentrate entirely upon the observable quantities—the steps, the pebbles, and their falling. He finds a mathematical expression which accurately correlates the height of the steps (energy levels) with the probability that a pebble will fall (radiate) from one step to another. To the mathematician this accurate formulation of the mathematical relationship between the observable quantities is a complete and satisfactory explanation or theory. The physicist, however, guided perhaps by instinct (which is the accumulated wisdom of the ages) rather than by formal logic, is not satisfied. He feels impressed but a bit confused by the logic of the mathematician, and also a bit distrustful. Down in his heart he feels that there must be something more than a law of probability that makes those pebbles drop. He goes to investigate. He finds the door of the building locked. He pushes; he knocks; he gets help; he rigs up a machine to batter down the door; he makes a small hole through which he sees signs of activity within the building; he builds a bigger and better battering ram; finally he breaks down the door and goes in. Within the building he finds a huge factory; giant cranes carry around great masses of material; enormous machines press, hammer, and draw this material into various shapes. Stupendous forces are at work. The building shakes, and from time to time a little pebble on the fire escape is shaken down from one step to another.

Successful as we have been in describing by equations much of the behavior of those extra-nuclear electrons that move in orbits far outside the nucleuses, we are still grossly ignorant of the most powerful elements of our material world.

So, perhaps, sometime may be resolved the peculiarities and puzzles of our present quantum theory—by small external manifestations of the enormous energy that we know to exist within the nucleus, but about which we now know too little even to make a guess as to how it may influence our present theories.

Be this as it may, where have we left the alchemist? We left him dead, killed by the chemist who had destroyed his hopes of effecting the transmutation of elements. But now the physicist has brought him to life again, with renewed vigor and enthusiasm. For if the atomic nucleus is a structure of electrons and protons, it should be possible to break up this structure or to add to it, and thus to change one chemical element into another. The agencies are no longer earth, water, air, and fire, but electricity and probably electrical particles shot with tremendous speeds into nucleuses.

A most significant event in this story was the discovery of radioactivity by Becquerel 36 years ago. Its significance became evident when Rutherford showed that the alpha and beta particles are, respectively, helium nucleuses and electrons shot out of the nucleuses of radioactive atoms with tremendous speeds, approaching that of light. Its significance became greater when Rutherford further showed that the parent atoms in thus ejecting these particles, transform into atoms of different chemical elements. The law of this transmutation was stated thus by Fajans: Expulsion of a beta particle changes the atom into the next higher one in the periodic table, and the expulsion of an alpha particle changes the atom into one which is 2 steps lower in the table. Here, for the first time, were authenticated cases of transmutation of elements.

The energies liberated in radioactive transformation are prodigious, in comparison with the amount of material involved. For example, radium continually gives off about enough energy to raise its own weight of water from freezing to boiling temperature every hour. By the end of 2,000 years it will be only half used up. By the time it is completely transmuted into its final products helium and lead, any given amount of radium will have generated an amount of heat equal to that from the combustion of 500,000 times its weight of coal. One pound of radium gives off enough energy to heat to boiling more than 13,000 tons of melted ice.

At first it appeared that here at last was in sight the goal of the alchemists. But, alas, there is one difficulty: The process is so slow. Suppose you have a gram of radium (a notable amount); you would have to wait 2,000 years to get half of its energy, another 2,000 years to get half of what is left, and so on. By that time you and your grandchildren long will have ceased to worry about a source of heat. Great as it is, the energy comes off so slowly that it leaks away and cannot be stored for use when wanted. As a practical source of energy it is useless. Alchemists and others have tried every physical and chemical agency that they could devise in an effort artificially to speed up radioactive processes, but without avail.

Today's goal is not gold and silver, but energy. And with the alchemist, who is a practical man trying to get something, is working the physicist, who is not an impractical man, trying to learn something. In fact they are one and the same man.

There are, however, some decided rays of hope, for artificial transmutation has been produced in 3 distinct ways, on a small scale. One of these dates back to about the time of the war, while the others both have been achieved within the past couple of years.

During the war the author was charged with arranging for the demonstration of a French device for locating submarines, for the benefit of British and American scientists engaged in the same problem. One of the British experts was Sir Ernest Rutherford. He sent word by the late Professor Bumstead, however, that he would be delayed through the necessity of completing certain laboratory experiments in which he thought he had split hydrogen nucleuses into 2 parts. "If this is true," he said, "its ultimate importance is far greater than that of the war." With true scientific caution, however, he asked us to keep this matter confidential, since he was not yet sure of his interpretation. This caution was justified, for his subsequent work showed that he had not broken up hydrogen nucleuses; but what he did find was equally significant, for he had succeeded in knocking protons out of the nucleuses of nitrogen, and various other light atoms.

Rutherford's success came not by luck, but by trained physical insight and persistence. Realizing that the possibility of success lay in bringing the largest possible electrical forces to act on the nucleus, he first found that radioactive substance which shot out alpha particles with the highest speed, and then let them shoot at the nucleuses of light atoms like nitrogen and aluminium. He chose these because of the relatively small electric charges of their nucleuses, which repelled the oncoming alpha particles less strongly and therefore permitted them to come closer than the nucleuses of heavy atoms would have done.

Under this vigorous electrical bombardment, some of the nucleuses gave out protons. These were detected by the sparks of light they produced on striking glass plates coated with special fluorescent materials. Their speed and their identification as protons were determined by measuring how far they would shoot through air and how much their paths were curved in a magnetic field. These protons may have been literally knocked out of the nucleuses by the impinging alpha particles, but from some nucleuses, as for example aluminium, the protons were shot out with much greater speeds than they possibly could have acquired from such impacts. It appears, therefore, that the bombarding alpha particle distorts the structure of the nucleus, which settles down into a new state of stability, shooting out the proton in the process. The alpha particle therefore serves as a sort of key to unlock the nucleus and release some of its energy. Ah, here we would seem to have achieved our goal; but no, the process is hopelessly inefficient as a practical source of energy. Only about one alpha particle in 600,000 happens to strike a nucleus in such a way as to produce a transmutation. The other 599,999 simply are scattered without apparently exerting any permanent effect on the nucleuses with which they come into contact.

The process of radioactive transmutation proceeds in its own characteristic slow, sure manner most provokingly unaffected by man's best, but puny efforts.

The second authentic type of transmutation is associated with the discovery of the neutron by Chadwick of Cambridge less than a year ago. For many years physicists have been led by logic to search for this neutron, and they have predicted some of its properties. For example we have atoms of atomic numbers from 92 down to 6, 5, 4, 3, 2, 1—uranium to carbon, boron, beryllium, lithium, helium, hydrogen—whose nucleuses have positive electric charges of 92 down to 6, 5, 4, 3, 2 and 1 units, respectively. Why should there not exist an atom of atomic number 0, with no charge on its nucleus? Such an atom would have no extra-nuclear electrons, and its nucleus would consist of equal numbers of protons and electrons (probably one of each) packed closely together. This atom would have no chemical properties and no physical properties of the usual type, which depend principally upon the electric field of the extra-nuclear electrons. It obviously would be hard to detect, would penetrate easily through even the densest materials, might readily penetrate through even the nucleuses of other atoms. The one thing it could do would be to "bump," for if it happened to strike head-on some other particle, such as a proton or an electron, it could deliver momentum to that particle by impact. If such a neutron particle should exist, not only would it be of the utmost interest as a new "building block" of atomic structure, but also it would be a most interesting tool, for it alone of all known particles could penetrate unopposed the sacred structure of nucleuses and perhaps knock out a key stone or foundation stone of their structure, causing their collapse. But the neutron would be a most unmanageable tool since, having no electric charge, we could not speed it up or control it by an electric field, as we do electrons, protons, and other ions. We would have to take it as we get it and simply watch to see what it does.

Rutherford's achievement in knocking protons out of light atoms was the first success attained in man's long struggle by his own efforts to change one element into another.

Well, Chadwick discovered this neutron and found that it consisted of one electron and one proton. It is like a hydrogen atom whose orbital or valence electron has been completely captured by the proton nucleus—a hydrogen atom shrunk down to almost nothing. For the preceding 4 years Bothe and his German colleagues had been playing with neutrons but did not know it, considering them to be photons, i. e., radiations of wavelength even shorter than the gamma rays of radium. Chadwick showed that, if the law of conservation of energy be true, they cannot be photons, and that their action on other atoms like nitrogen or argon is exactly what would be expected if they be neutral material particles of mass 1, i. e., neutrons. When these neutrons bump into nitrogen, argon, and other atoms, they knock them forward by just the amounts that would be calculated from the laws of impact of balls of mass 1 against balls of mass 14, 40, etc.

This is how the neutron was produced. The Kelly

One striking feature of the transmutation associated with the discovery of the neutron is that the products are heavier atoms than the original atoms. This is a process of atom building, and not atom disintegration as in the previously known cases of transmutation, radioactivity and Rutherford's artificially produced nuclear disintegration. It is highly important to know that atoms may be built up as well as broken down.

Hospital in Baltimore gave Chadwick a lot of old radium emanation tubes that had lost their activity for therapeutic purposes, but which contained the radio active residues. From these tubes Chadwick extracted polonium, an element that ejects alpha particles of extremely high speed. This polonium was spread over a small plate placed about 2 cm away from a plate of beryllium, so that the beryllium was subjected to bombardment by the fast alpha particles from the polonium. It then was found that the beryllium emitted rays of a tremendously penetrating nature, which had the power of ionizing any gas through which they passed and of knocking forward those atomic nucleuses that they happened to hit. All this was studied by means of ionization devices known as Geiger ion counters, or by scintillations produced on fluorescent screens. These rays are the neutrons. Written as a chemical equation, the process is

$$\mathrm{Be}\,(9) + \mathrm{He}\,(4) = \mathrm{C}\,(12) + n\,(1) \tag{1}$$

Similarly boron behaves like beryllium in giving off neutrons according to

$$\mathrm{B}\,(11) + \mathrm{He}\,(4) = \mathrm{N}\,(14) + n\,(1) \tag{2}$$

Here the alpha particle is, of course, a helium nucleus of mass 4, and the products of transmutation are carbon, nitrogen, and neutrons.

The third and last success of the modern alchemists, to date, was the transmutation of lithium when bombarded by swift protons by Cockroft and Walton early in 1932. Here the reaction is

$$\mathrm{Li}\,(7) + \mathrm{H}\,(1) = 2\,\mathrm{He}\,(4) \tag{3}$$

This is peculiarly interesting for several reasons. In the first place it is the first instance of transmutation produced by a particle whose speed had been produced by laboratory methods. In the previous cases the bombarding projectiles were alpha particles whose speeds were fixed beyond man's control by the inherent nature of the radioactive process, except that man could slow them down as desired by interposing absorbing screens in their path. In the present case, however, protons produced by ionization of hydrogen and speeded up by applied voltages up to 600,000 volts were used as the bombarding agents.

In the second place, such a source of bombarding particles may be made ever so much more powerful than the previous sources of alpha particles, for currents of micro-amperes or even milliamperes of protons may be used instead of the tiny natural currents of alpha particles which, from high speed sources like polonium, come out at the rates of only a few thousand or hundred thousand particles per second. Thus we may hope to carry on these transmutation processes on a chemical rather than an atomic scale.

In the third place, the proton has only half the charge of an alpha particle and therefore suffers only half the repulsive force as it approaches an atomic nucleus. For this reason we can hope to shoot protons much farther into nucleuses than alpha particles can penetrate. Protons thus have in a certain measure the advantage of neutrons, which are not repelled at all, and the great advantage of their capability of use at controllable speeds and quantities.

The final interest to the author, personally, in this type of transmutation, is the fact that it was the first of a group of transmutations predicted by Dr. Van de Graaff in a report made to the author about 3 years ago, and on the basis of which he sought further facilities for developing the high voltage generator on which he then was experimenting. He not only predicted the transmutation, but also the resultant energy liberation of 16,000,000 volts. He did not predict how speedy the protons would have to be to effect this transmutation, for there was no basis upon which to calculate it; I think every one was surprised to learn that Cockroft and Walton detected it with proton energies as small as 125,000 volts. At 250,000 volts about one atomic transmutation was found for every thousand million protons that were shot into the lithium. At higher proton velocities the number of transmutations increased. In every case, however, the helium nucleuses produced had about 8,000,000 volts energy apiece, or 16,000,000 for the pair. It was as if the proton, upon entering the lithium nucleus, combined with it to produce 2 helium nucleuses with repulsive forces between them so great that they flew apart with this tremendous 16,000,000-volt energy.

Mass and energy are interconvertible; if mass disappears, energy takes its place in accordance with eq 4. In more familiar terms, $2.13(10)^{13}$ calories of energy are liberated for every gram of matter that vanishes.

How was Van de Graaff able to predict this energy? How, in fact, can all of the energies in atomic transformations be predicted, for they can be predicted in radioactive processes and in the other cases described in eqs 1, 2, and 3? The answer to this question lies in an equation, a product of Einstein's genius and perhaps the most important aspect of his whole theory of relativity. Contrary to the much published statement that only 12 people in the world could understand his theory of relativity, this part of the theory is simple, though perhaps the argument through which the conclusion was reached is more complicated. The equation is, simply

$$E = M\,c^2 \tag{4}$$

or energy = mass × (velocity of light)^2 or ergs = grams × $9(10)^{20}$.

In more common language, the annihilation of one

pound of matter would create enough energy to heat one hundred million tons of water from freezing to boiling temperatures. Such are the stores of atomic energy. Let us see how this works in reference to the preceding case of transmutation.

A certain isotope of lithium has atomic weight 7.007 and a proton has atomic weight 1.0077; their sum is 8.0157. This splits up into 2 helium nucleuses each of mass 4.00. Thus the product nucleuses have mass 0.0157 less than the original combining nucleuses. This lost mass is converted into energy according to eq 4. To calculate the energy, we first change 0.0157 from chemical units of atomic weight into grams, which gives a loss of $2.83(10)^{-26}$g for every individual transmutation process. According to eq 4 this is equivalent to the liberation of $25.5(10)^{-6}$ ergs. This is the amount of energy that would be acquired by an electron in moving through a potential difference of 16,000,000 volts, which is what we mean by 16,000,000 energy. Thus, by considering various atomic weights in connection with Einstein's equation, we gain a clue as to which atoms may be expected to be relatively easily transmuted, and what the resultant energy will be.

This brings the discussion to its final stage. With these promising beginnings, just recently achieved after centuries of effort, the alchemist takes renewed hope and enthusiasm in his quest. He now has some knowledge of how to plan his attack on the atom. He has at least 2 proved weapons, or rather missiles to hurl at atoms: alpha particles from radioactive sources; and ions that are given tremendous speeds with high voltages (such as protons). He will continue to batter away at the atoms with both of these. Of the 2, the high voltage ion source is the most intriguing on account of the almost unlimited possibilities of high speeds, through the development of high voltage generators, and of high intensities, through the development of potent sources of protons or other types of ion.

It is this feature that gives particular interest to the various new types of high voltage generators that now are being developed in various laboratories. Most promising are those of Lawrence at the University of California, and of Van de Graaff at Princeton University and at the Massachusetts Institute of Technology.

Lawrence does not actually use or develop a very high voltage, but he uses a moderate voltage to give a succession of pushes to the ions until they get to going with speeds that have considerably exceeded 1,000,000 volts, and that may well reach 5,000,000 volts with apparatus under construction. Without going into technical details, the idea may be conveyed by likening the operation to a child in a swing. By properly synchronizing the pushes, the child may be made to swing very high, even though each individual push would lift him only a short distance. Similarly, a voltage of 10,000 volts, applied 100 times in succession to an ion traveling around in a circle under the influence of a magnetic field, will give it the same final energy as if 1,000,000 volts had been applied once.

The field is open, and relatively so little explored that we cannot predict what will be discovered. But we should not be surprised if the next generation should uncover the most exciting and far-reaching developments in the whole history of science.

Van de Graaff has gone back to electrostatic principles and developed a d-c generator in which electricity at low voltage is sprayed onto a rapidly moving insulating belt that carries it up into a spherical terminal upon which it is deposited. The charge and potential of the terminal thus rise up to the point at which further increase is limited by the breakdown of the surrounding insulation. The voltage limitation is therefore that inherently determined by the geometry of the electrodes and the character of the surrounding insulating medium, while the current is limited to the rate at which electric charge is transported by the belts. After successful operation to 80,000 volts of a small generator made of tin cans, sealing wax, and a silk ribbon, a larger generator was built to deliver 30 μamp at 1,500,000 volts. It was successful, as also have been similar and modified generators built during the past year in several laboratories.

The most ambitious of these generators is one designed to deliver 30 or 40 kw at voltages calculated to be 15,000,000 volts and expected to reach at least 10,000,000. This is nearing completion in the Massachusetts Institute of Technology experiment station on the estate of Col. E. H. R. Green at Round Hill, Mass. The terminals are 15-ft polished aluminum spheres, mounted on 30-ft "textolite" insulating cylinders inside of which run the belts that convey the charge to the spheres. Each sphere is a laboratory room, within which the experimenter can assemble and operate the apparatus that bridges the gap between the positively and negatively charged spheres.

Although this Round Hill outfit is quite spectacular, it is probable that the most important developments of this apparatus will be not in the open air but in some container filled with a medium of superior electrical breakdown strength. The voltage increases directly and the power output directly as the square of this breakdown strength. Two such modifications already have been operated successfully in small models, one operating in the best attainable vacuum and the other in gas at about 30 atmospheres pressure.

This completes the story of the "Battle of the Alchemists" to date. They have matched their skill, strength, and all the resources of science against the dogged integrity of the atom for many centuries. Within the last 10 years, but mostly within the last 2 years, it has begun to look as if the atom may succumb all along the battle front, even as it already has surrendered 3 strategic outposts.

Meanwhile Rutherford, Chadwich, Cockroft and Walton, Lawrence, Van de Graaff, Bothe, and many others continue the work. They are the modern alchemists, direct descendants of the alchemists of the middle ages and tracing their ancestry back to Hermes and the fallen angels.